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A new species of *Streptocephalus* Baird, 1852 (Crustacea, Branchiopoda) from Peninsular India

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Abstract

The Indian subcontinent contains six of the more than 60 species of the fairy shrimp genus *Streptocephalus* Baird, 1852. Three of these occur in the western parts of peninsular India. Recent studies from the megadiverse Western Ghats have revealed a seventh *Streptocephalus* species from the Indian subcontinent and the second from the Northern Western Ghats (NWG). *Streptocephalus warliae* **sp. nov.** is described and compared with related South and Southeast Asian species. The males exhibit a distinct triangular basomedial projection at the base of the second antenna distal antennomere, whereas the females have a deep apical notch at the tip of their second antenna. *Streptocephalus warliae* **sp. nov.** is so far known only from its type locality and may have a limited geographic range. We provide a modification to the key of Indian *Streptocephalus*. Considering the increasing urbanisation in the region, we suggest a red listing of the species.

Key Words

Conservation, endemic, large branchiopods, red listing, *Streptocephalus sirindhornae*, *Streptocephalus warliae* sp. nov.

Introduction

Fairy shrimps (Anostraca) are a group of crustaceans frequently found in ephemeral aquatic environments that have evolved to live in such habitats (Belk and Brtek 1995; Dararat et al. 2011; Rogers 2013, 2015; Padhye et al. 2017). *Streptocephalidae* Daday, 1910, is the most diverse anostracan family, comprising a single genus, *Streptocephalus* Baird, 1852, and currently recognised as having over 60 species (Rogers and Padhye 2014; Rogers 2024). Streptocephalid species are found in Africa, Eurasia, Australia, and North America, with Africa harbouring the highest diversity (Rogers 2015, 2024). A significant gap remains in our knowledge of their diversity and distribution across the extensive Asian region (Rogers and Padhye 2014; Padhye et al. 2017; Shu et al. 2018). At present, there are eleven known *Streptocephalus* species in Asia, including five from the Southeast Asian (SEA)/Indochina area and six from the Indian subcontinent (Rogers 2013; Rogers et al. 2013; Rogers and Padhye 2015; Shu et al. 2018).

The Western Ghats of India are among the most species-diverse areas globally (Mittermeier et al. 1998) and include distinct environments such as rocky outcrops that support a high variety of endemic large branchiopods and cladocerans (Rogers and Padhye 2014; Padhye et al. 2015; Padhye and Ghate 2016; Van Damme and Padhye 2024). In one of our recent surveys, we discovered a fairy shrimp that closely resembles *S. sirindhornae* Sanoamuang, Murugan, Weekers & Dumont, 2000, a species commonly found in Southeast Asia (Sanoamuang et al. 2000; Shu et al. 2018). In this work, we offer a comprehensive morphological description. We summarise the importance of conducting comprehensive biodiversity surveys for these 'flagship' crustaceans to address the clear 'Linnean shortfall' in the Western Ghats (Hortal et al. 2015).

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Materials and methods

Field methods

A roadside pool (Fig. 1A) on the Jawahar plateau (Palghar, Maharashtra) was sampled for the presence of large branchiopods in August and September 2024 using a rectangular hand net (30 × 60 cm) with 150-µm mesh size, attached to a telescopic pole. Collected specimens were immediately stored in either absolute alcohol or 4% formaldehyde solution for molecular and morphological study, respectively. Environmental parameters were recorded on-site using a multiparameter probe (PCSTestr 35, Thermo Fisher Scientific Inc.). Locality coordinates were obtained on-site using a Garmin GPS device (Garmin eTrex 10). A map (Fig. 1B) was prepared using the '*leaflet*' package in R.

Lab methods

The specimens were observed under a Micron Optic Prime stereo microscope (Micron Instrument, Saha, Haryana, India) and a Magnus MX21 trinocular compound microscope (Magnus Opto Systems India, India). Images were captured using a Magnus MagCam DC-5 digital camera (Magnus Opto Systems India, India), stacked using the Helicon Focus software (https://www.heliconsoft.com/), and processed in the image editing software GIMP (https://www.gimp.org/). The vector graphics editing software Inkscape (https://inkscape.org/) was used to make drawings.

The eggs and specimen parts were processed for scanning electron microscopy (SEM) using the hexamethyldisilazane (HMDS) method by Nation (1983). The dried samples were platinum-coated, and SEMs were taken on the JEOL Analytical Scanning Electron Microscope (Model JEOL JSM-6360, JEOL, Akishima, Japan) at an accelerating voltage of 10 kV.

Identification, nomenclature, and comparative morphological data for *Streptocephalus* Baird, 1852, were based on Sars (1900), Bond (1934), Sanoamuang et al. (2000), Velu and Munuswamy (2005), Rogers and Padhye (2014), Shu et al. (2015, 2018), and Rogers and Meyer-Milne (2021). Terminology follows Shu et al. (2018).

Voucher specimens of the species have been deposited in the Western Regional Centre of the Zoological Survey of India (ZSI-WRC, Akurdi, Pune 411044, Maharashtra, India).

We sequenced three species – *Streptocephalus warliae* sp. nov., *S. sahyadriensis* Rogers & Padhye, 2014, and *S. dichotomus* Baird, 1860 – and deposited them in GenBank (materials and methods regarding sequencing and accession numbers are provided in Suppl. material 1). However, due to a limited amount of sequence data, we did not include a phylogenetic tree in this study; this will be part of further investigation.

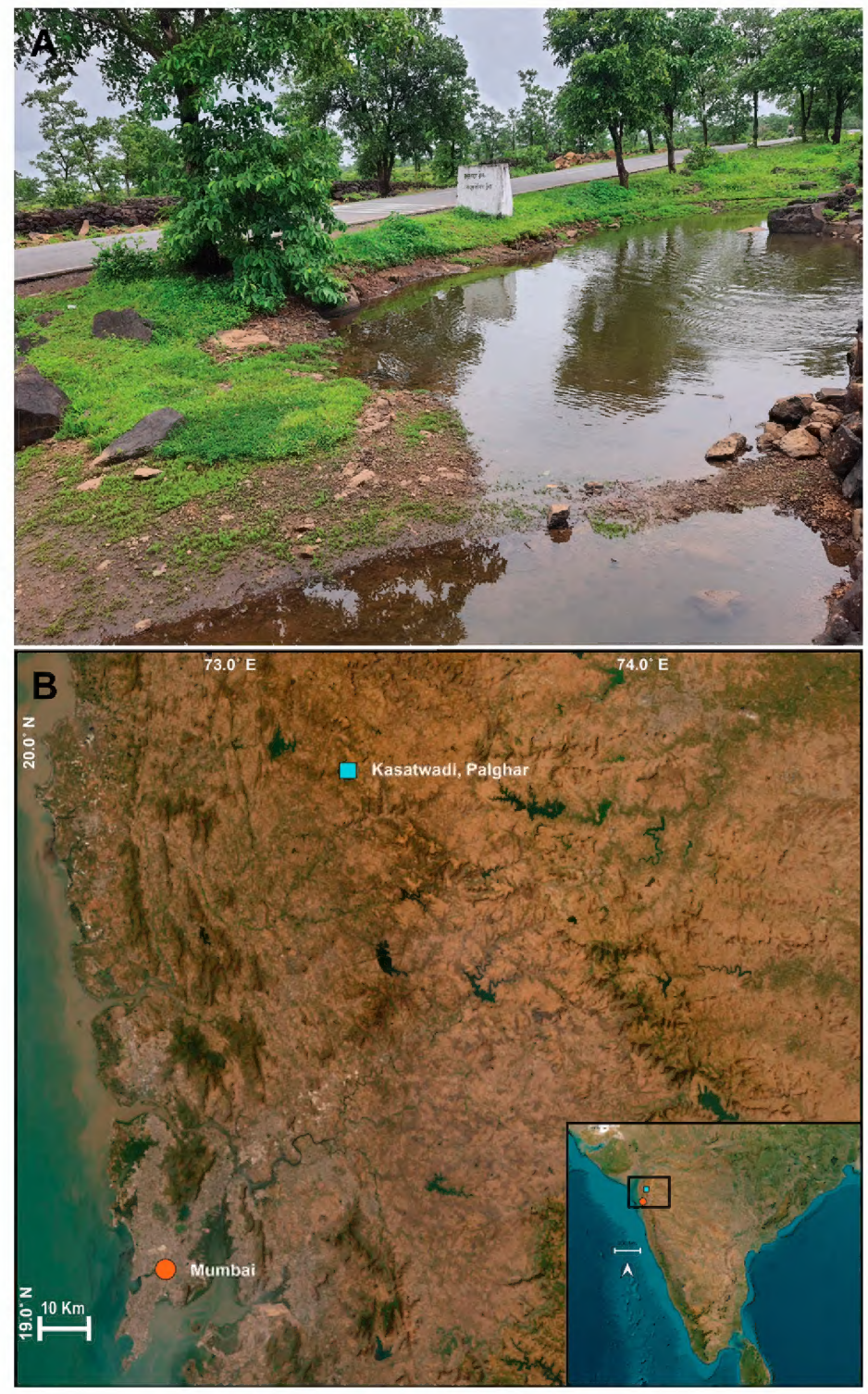

Figure 1. A. Type locality of *Streptocephalus warliae* sp. nov. from Jawahar plateau (Palghar, Maharashtra, India); **B.** Map showing the type locality of *Streptocephalus warliae* sp. nov., the type species in peninsular India.

Taxonomic account

Order Anostraca Sars, 1867
Family Streptocephalidae Daday, 1910
Genus *Streptocephalus* Baird, 1852

***Streptocephalus warliae* Katke, Padhye & Vanjare, sp. nov.**

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Figs 2–7

Type material. ***Holotype*** • 1 male (ZSI-WRC C.2582, Zoological Survey of India, Pune, India). ***Allotype*** • 1 female (ZSI-WRC C.2583 Zoological Survey of India, Pune, India) same data as holotype. ***Paratype*** • 2 males (ZSI-WRC C.2584, Zoological Survey of India, Pune, India) same data as holotype. Preserved in alcohol.

Diagnosis. *Streptocephalus warliae* sp. nov. belongs to the "*S. dichotomus*" species group and can be separated by the following characters: second antenna distal

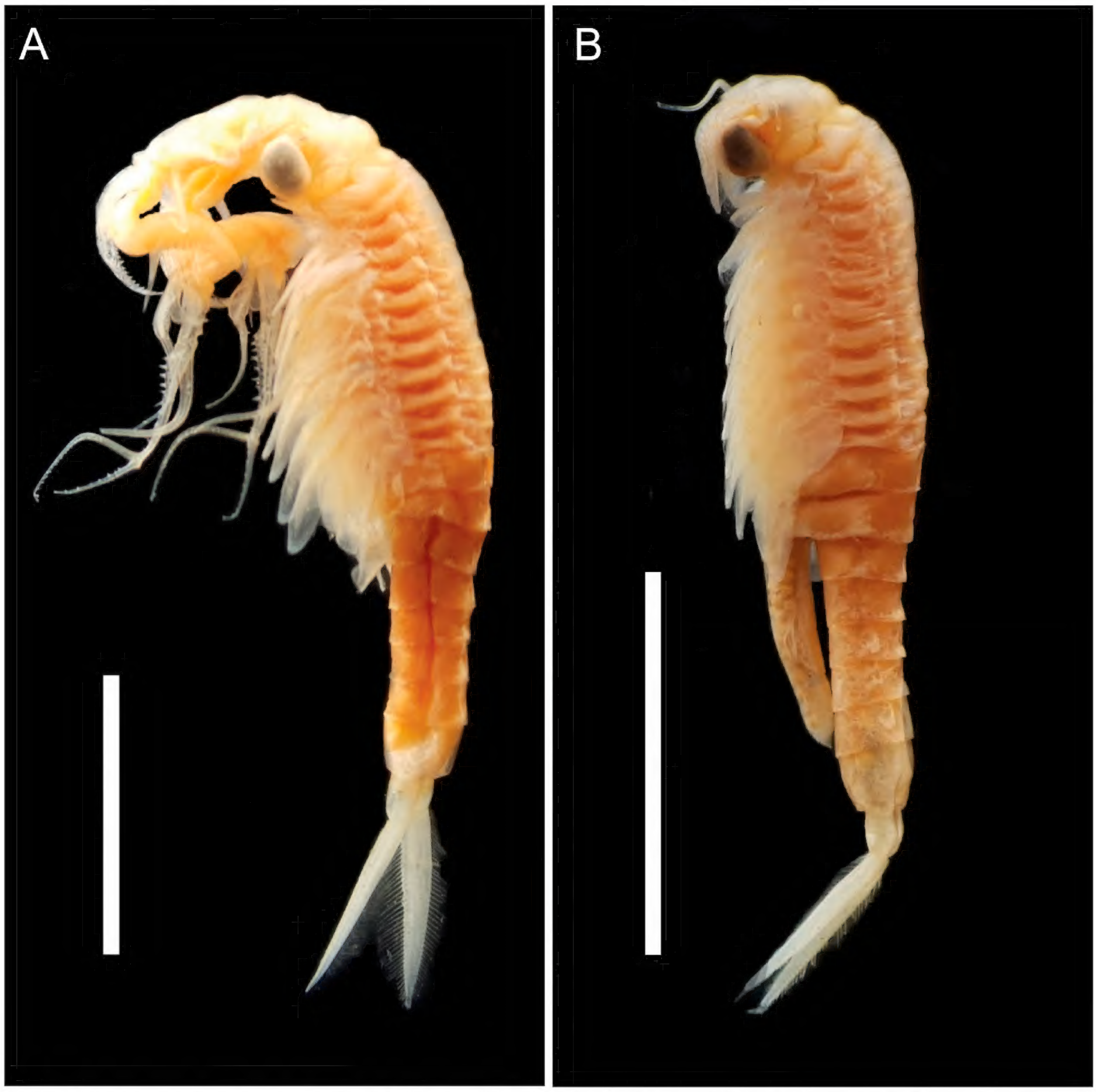

Figure 2. *Streptocephalus warliae* sp. nov. **A.** Male holotype (lateral view); **B.** Female allotype (lateral view). Scale bar: 10 mm.

antennomere with an obtuse, subconical, basomedial projection. Antennal appendage peduncle with 4–5 elongate, dorsobasal papillae in a subtransverse row, each papilla conical and flexible, with all but the lateralmost one smooth, extending halfway along the peduncle. Lateral most dorsobasal papilla distoventrally with longitudinal row subpapillae, reaching to end of peduncle. Peduncle dorsomedially with longitudinal row of 11–14 spiniform processes reaching base of "hand". The margin of the posterior lateral branch (lower finger) is smooth. The margin of the posterior primary branch (upper finger) of the posterior ramus (finger) bears major and minor spines, divided distally into two unequal apical rami (digits) with the upper ramus at a sharp 90-degree angle with the primary branch. The curved upper rami are pustulate, whereas the lower straight rami margin is with unequal-sized aciculate spines. Posterior branch (spur) of the anterior ramus (thumb) ends in unguiform structure distally. Anterior ramus without a distal triangular projection. Female second antenna with a distinct deep notch towards the apical end.

Description of the holotype. Average body length (from front of head to tip of telson) 19.1 mm (n = 20), range 11–26 mm (Fig. 2A).

Head typical for genus, frontal appendage, triangular, simple and short. First antenna filiform, length 35% longer than second antenna proximal antennomere; apex pointed with 7 small setae at the tip and 3 long setae subapically.

Second antenna typical of the genus (Figs 2A, 3A, B). A distinct triangular basomedial projection at the base of distal antennomere (Figs 3A, B, 5A). Antennal pedun-

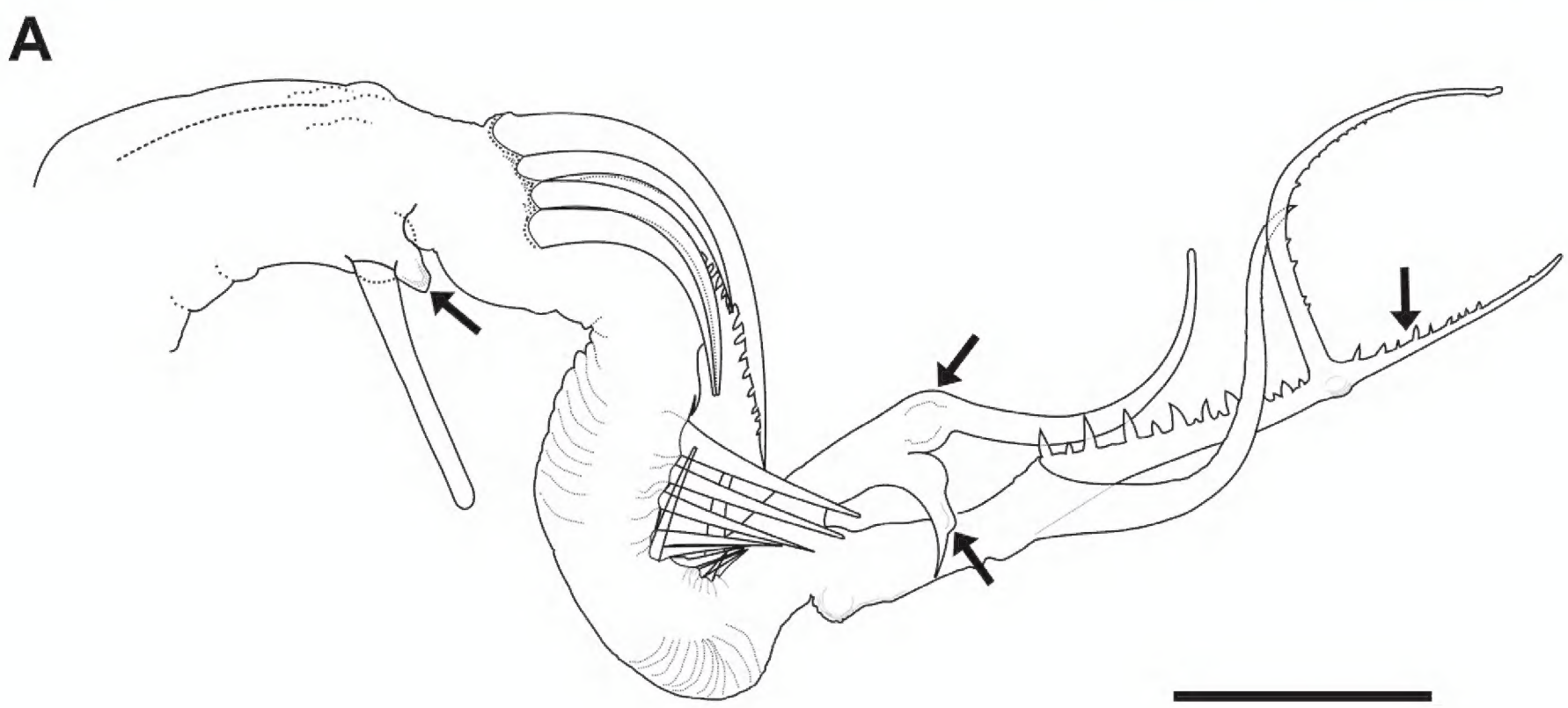

Figure 3. *Streptocephalus warliae* sp. nov. male: **A.** Second antenna lateral (outer view)**; B.** Second antenna lateral (inner view). Scale bars: 2 mm.

cle with anteriomedial dorsobasal papillae, 4 (30%) – 5 (70%) in number, with papillae ventrally, reaching end of peduncle (Figs 3A, 5A, B). Antennal appendage peduncle laterally with 11–14 spiniform processes (slender process) (Figs 3A, 5A, B, D). Length of the longest spiniform processes 1.8–2.0 mm, subequal to length of proximal antennomere. Peduncle anteriomedially and ventrally (near the spiniform processes) with triangular protuberances; eight such protuberances ventrally and six anteriomedially (Fig. 5B, C). Antennal appendage apical cheliform structure (hand), not broadened at the base of the anterior ramus (Figs 3A, B, 5D). Anterior ramus and posterior branch without spines. Anterior ramus without distal lamellar projection (Figs 3A, B, 5D). Anterior ramus posterior branch broadly lamelller, not constricted apically, ending in ungiform structure (Figs 3A, 5D).

Posterior ramus ventral margin with emargination near to the confluence of both rami, emargination ~1.2 times as deep as wide (Fig. 5D). Posterior ramus branched/biramous, length ~1.2 times anterior ramus. Posterior ramus with a dorsolateral (lower) arcuate subramus (Fig. 3A). Posterior primary branch bearing acute major and minor spines, major spines up to ~6 times longer than minor. Primary branch distal end divided into two unequal apical rami (Figs 3A, B, 5A, 6A). The curved upper rami arcuate, margin smooth, with or without small basal spines, distal 50% pustulate, and angled 90 degrees from posterior primary branch. The lower straight ramus ~1.2 times smaller than the upper ramus, lined with unequal aciculate spines in proximal half of proximal region (Fig. 4A). Posterior lateral branch margin smooth (Fig. 3A, B).

Trunk limbs typical for genus (Fig. 4C, D). Endite 1 of first and fifth pair of limbs with filter comb and, at posterior side, with scraping spine and naked tactile seta.

Genital segment and gonopods as in *S. dichotomus* group. Genital segments smooth, with lateral linguiform

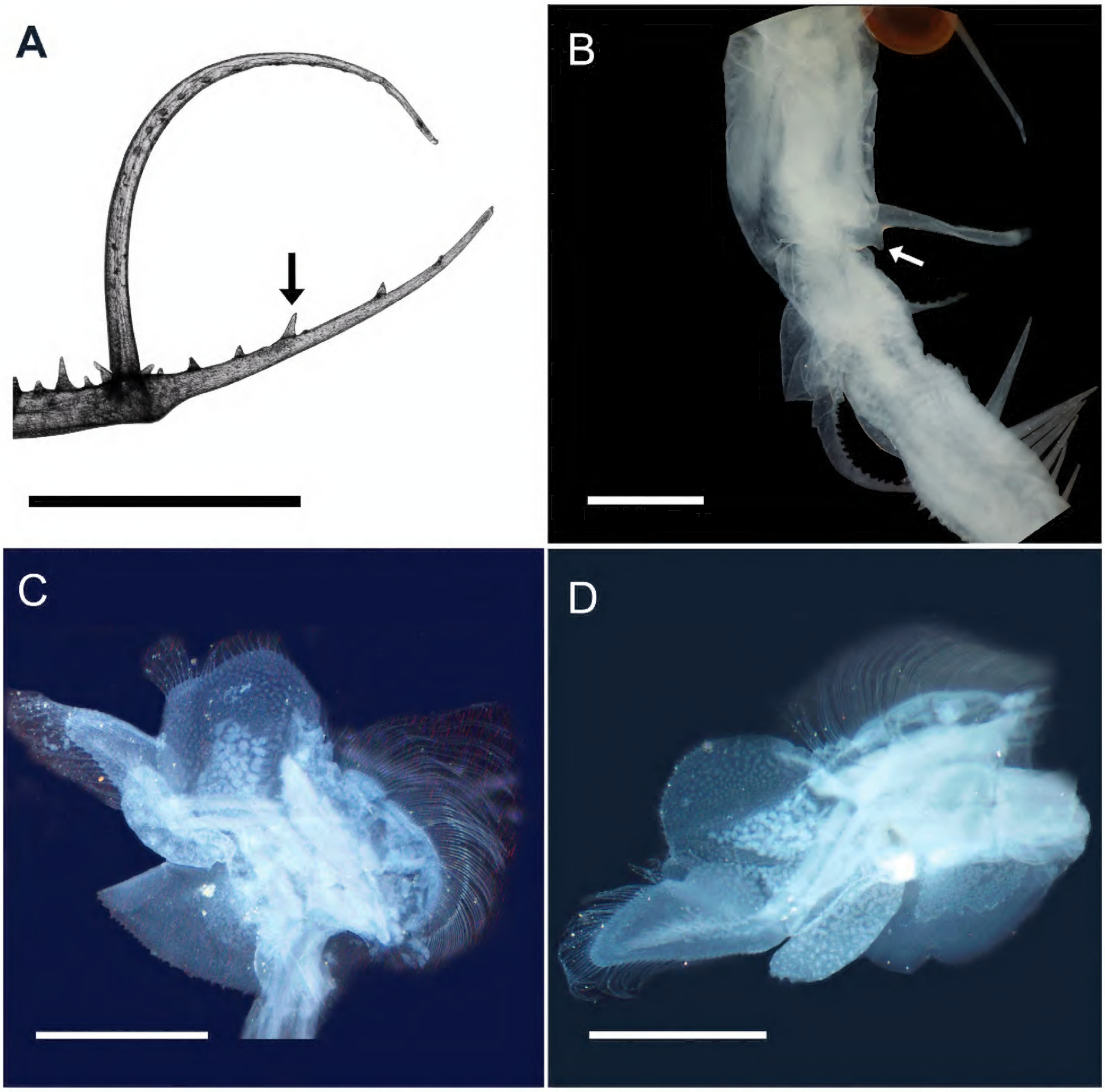

Figure 4. *Streptocephalus warliae* sp. nov. male: **A.** Upper and lower ramus of posterior primary branch, showing pustulations and spines, respectively; **B.** basomedial projection at the base of distal antennomere (highlighted with an arrow); **C.** overview of Trunk limb 1; **D**. overview of Trunk limb 5. Scale bars: 2 mm (**A**); 1 mm (**B–D**).

outgrowths. Gonopod cylindrical, with a basomedial spiniform outgrowth, bearing four denticles medially (Fig. 5E).

Abdomen and cercopods as in *S. dichotomus* group (Fig. 2A).

Description of the allotype (female). Body slightly smaller than male, body length from 13.0–21.0 mm, average 17.3 mm (Fig. 2B).

First antenna 2.4 times length of eye plus peduncle, 1.2 times length of second antenna, apex pointed with 4–7 small at the tip, three long setae just below the apex (Fig. 7D).

Second antenna slightly broad, elongated (length-to-breadth ratio is >1.9 measured from centre), spatulate, with sparse setae on the distal margin and a distinct notch near the apical end (Figs 6A, B, 7A).

Cercopods setose (Fig. 6D).

Ovaries uniramous; brood pouch elongate and fusiform; extending from segment III to half of segment V. The genital opening of the pouch terminal (Fig. 6C).

Description of Egg. Eggs spherical; surface with irregular and variable polygons; ridges raised, central field depressed; ~180 μm in diameter (Fig. 5F).

Ecology. The roadside basaltic rock pool was 6 × 3 m in area and ~1 m deep. It has submerged vegetation (*Hydrilla* sp.), tadpoles, and aquatic beetles. No other large branchiopods were seen co-occurring with this species. The pool is surrounded by many such smaller pools and a few small stone quarries. The cattle utilise the pool for both drinking and bathing, and as a tourist spot, the area attracts many visitors. The water temperature ranged

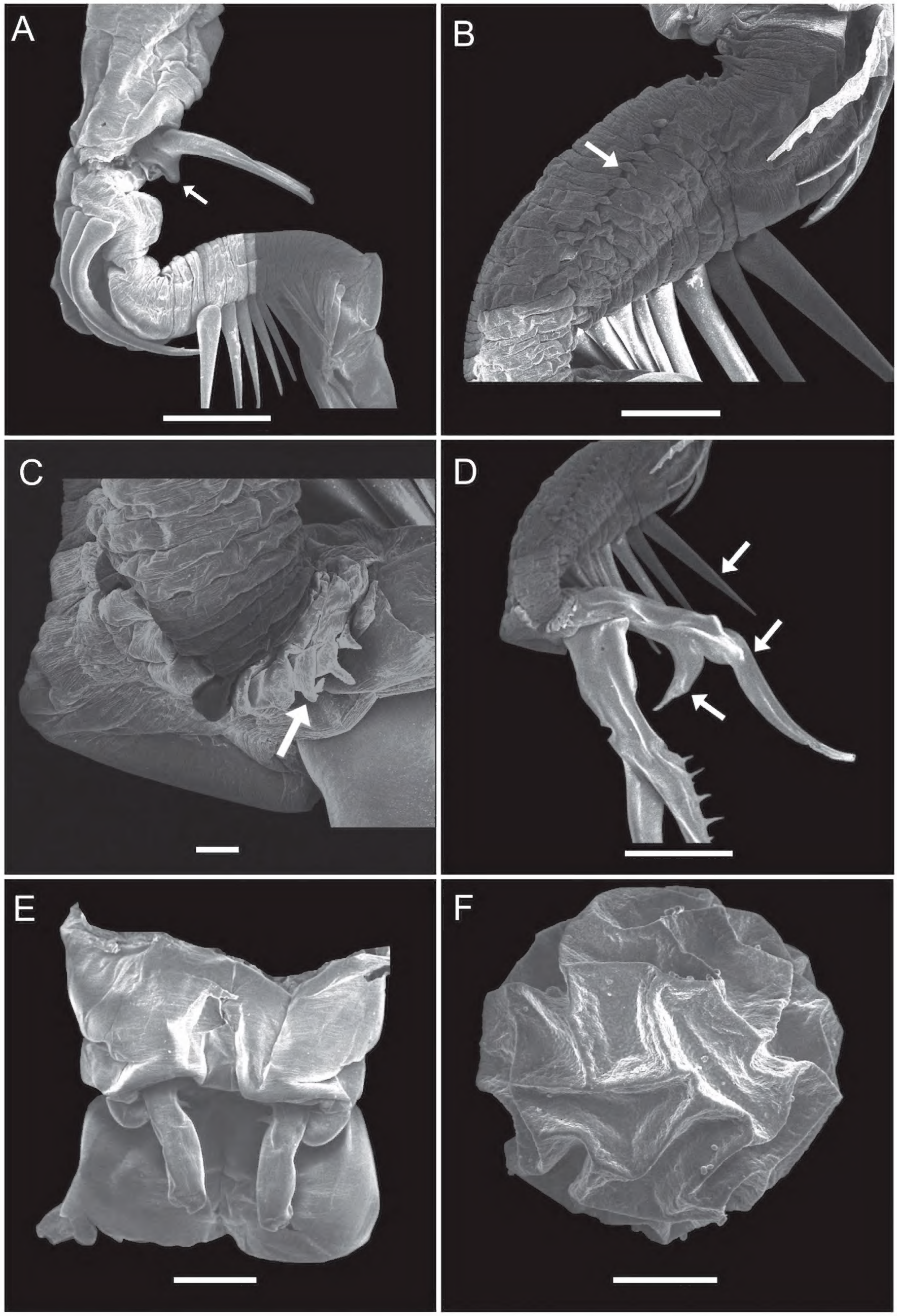

Figure 5. SEM of *Streptocephalus warliae* sp. nov. **A.** Basomedial projection at the base of distal antennomere along with antennal dorsobasal papillae and spiniform processes; **B.** Triangular anterio-medial and spiny medial protuberances on the peduncle; **C.** Triangular protuberances on the ventral side of peduncle; **D.** Anterior ramus and posterior branch; **E.** Male genitalia with the lateral linguiform outgrowth; **F.** External morphology of the egg. Scale bars: 1 mm (**A, C, D**); 500 µm (**B, E**); 50 µm (**F**).

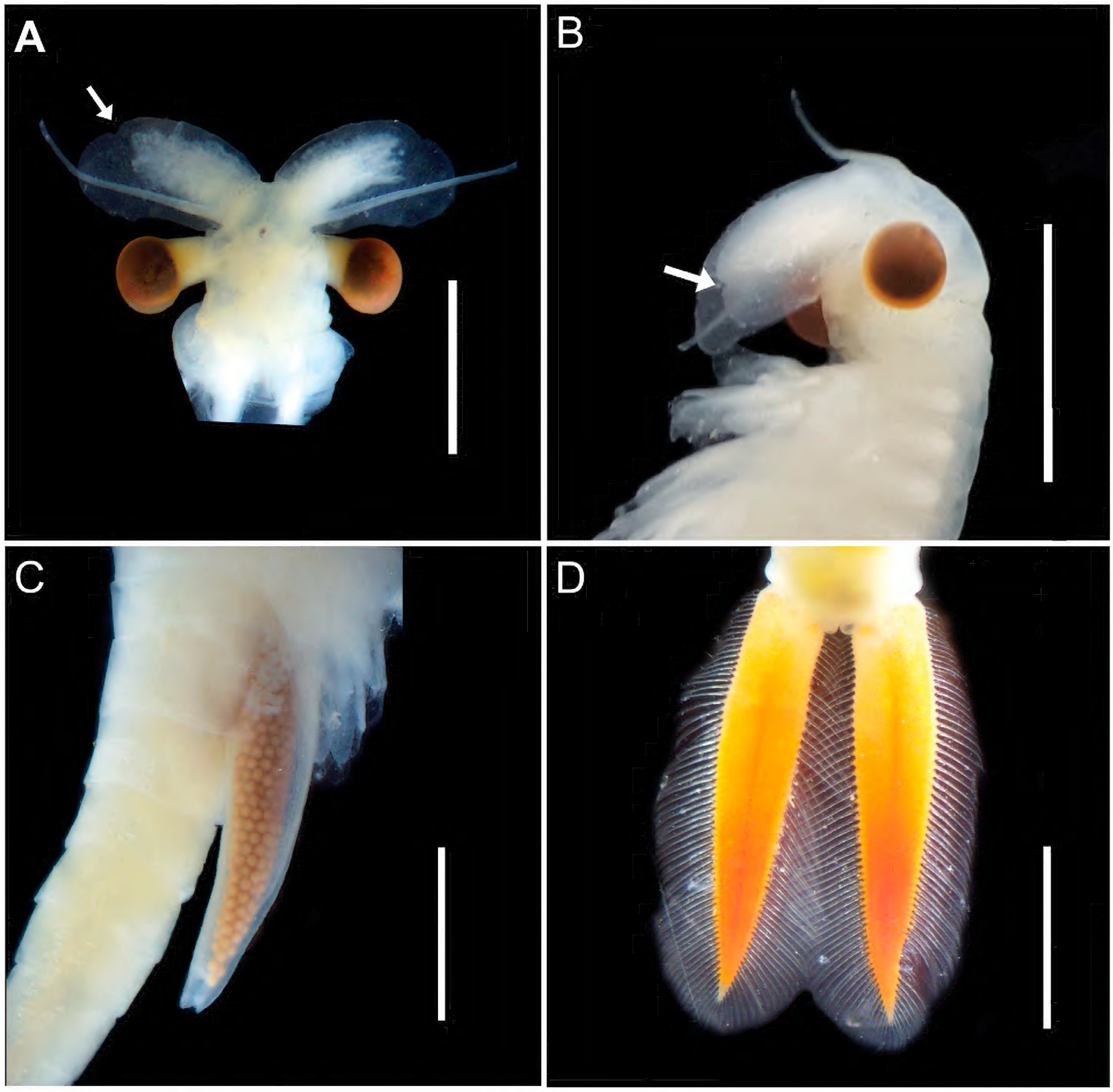

Figure 6. *Streptocephalus warliae* sp. nov. female: **A.** Head (dorsal view) showing eyes, first antenna, and second antenna; **B.** The distinct notch on the apical end of second antenna (left lateral view); **C.** Brood pouch showing the terminal genital opening (lateral view) **D.** Cercopods (dorsal view). Scale bars: 2 mm (**A, B, D**); 5 mm (**C**).

between 22.0 °C and 23.9 °C, pH between 7.2 and 7.4, and salinity between 27 ppm and 36 ppm.

Etymology. The name is dedicated to the indigenous 'Warli tribe' residing in and around the type locality. The tribal women are known for creating distinctive wall paintings, popularly known as the "Warli painting," using natural materials like rice paste, gum, and red soil. The use of circles, triangles, and squares in the paintings reflects their close association with "mother nature."

Distribution. This newly discovered species is currently known only from its type locality, an unnamed roadside pool situated on the lateritic plateau in Jawahar, Palghar district, Maharashtra state (India). Elevation 420 m, coordinates 19°53'09.1"N, 73°11'25.5"E.

Remarks. The male second antenna morphology of this species partly resembles that of *S. sirindhornae* and *S. dichotomus*. Still, this species possesses certain unique characteristics not observed in either. This species stands out from all other Indian species by the presence of a distinct triangular basomedial projection present at the base of the proximal antennomere, while the characters like a) aciculate minor and major spines on the posterior primary branch margin, b) sharp 90° angle of the upper bifid ramus to the posterior primary branch, and c) lower bifid ramus margin of the posterior primary branch with spines instead of pustulations separate the species from *S. sirindhornae*. The absence of distal lamellar projection on the anterior ramus and protuberances on the ventral and anteriomedial sides of the peduncle and the deep notch on the female second antenna apical end are other characteristics that separate *S. warliae* sp. nov. from the other Indian *Streptocephalus* species (see Table 1 for important differences). The apical setal number

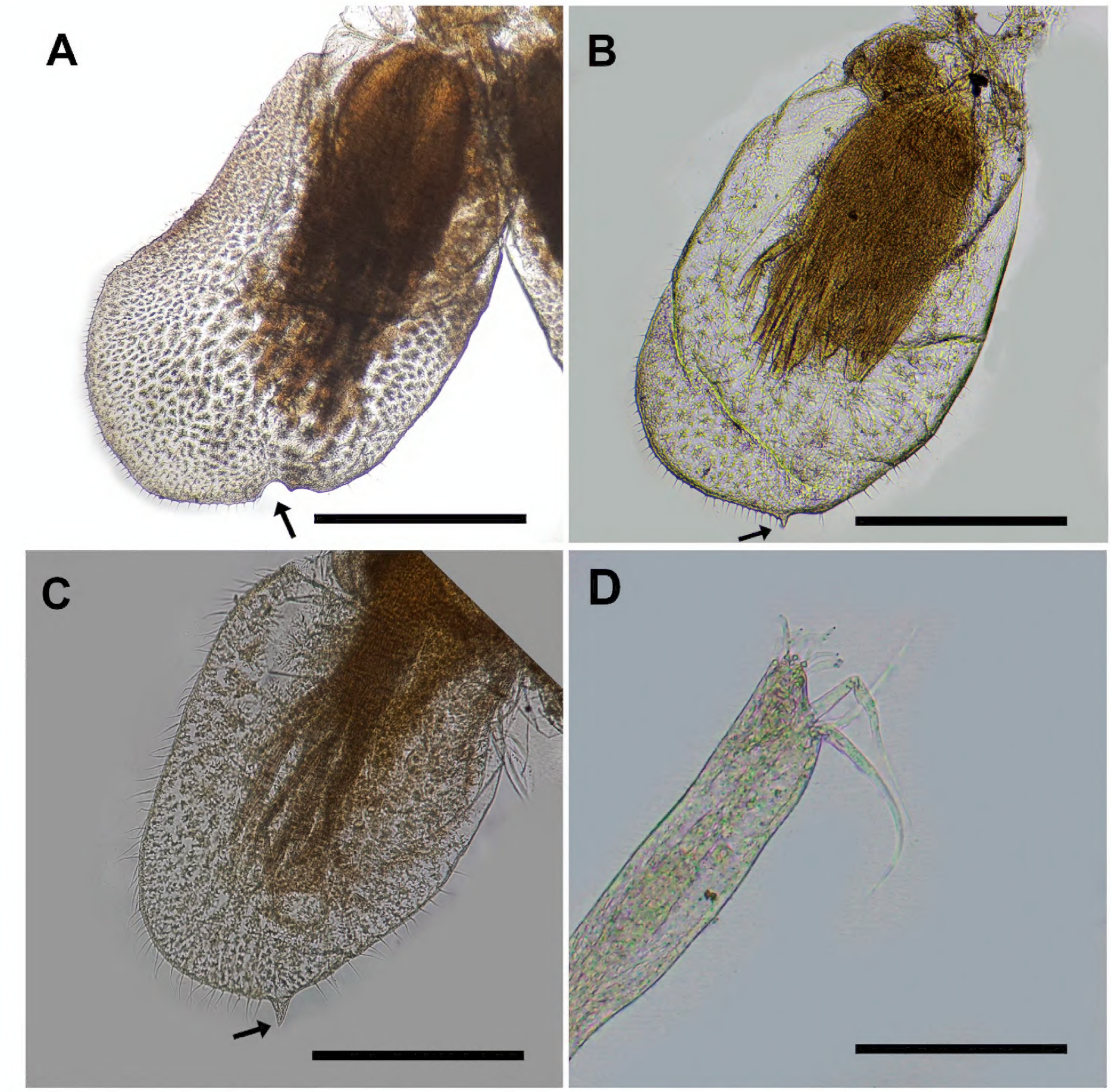

Figure 7. A. Second antenna (dorsal view) of *Streptocephalus warliae* sp. nov. showing the distinct notch on the apical end; **B.** Second antenna (dorsal view) of *S. sahyadriensis* small triangular protrusion; **C.** Second antenna (dorsal view) of *S. dichotomus* showing the distinct triangular protrusion; **D.** Tip of the first antenna of *Streptocephalus warliae* sp. nov. showing the 3 long, subequal setae and 4–7 small subequal setae. Scale bars: 1 mm (**A**); 0.5 mm (**B, C**); 0.1 mm (**D**).

on the second antenna in the females with 4–7 short subequal setae on the apex (eight in *S. sahyadriensis* and 5–8 in *S. dichotomus*) and with three long and subequal setae right below it in our specimens, *S. sahyadriensis* and *S. dichotomus*. In *S. shinsawbuae* Shu, Rogers, Chen & Sanoamuang, 2018, only the three long setae were documented (see Shu et al. 2018). The genital opening of the pouch is in the terminal region, whereas Kraus et al. (2004) reported it to be subterminal in *S. torvicornis* (Waga, 1842).

Discussion

Streptocephalus warliae sp. nov. represents the eighth species documented within the '*S. dichotomus* group' (Shu et al. 2018). This finding increases the count of Oriental *Streptocephalus* species to 12, with the Indian subcontinent hosting the highest diversity at seven species (Rogers and Padhye 2015), compared to five species from SEA. In terms of distribution, *S. dichotomus* and *S. sirindhornae* are the most prevalent species in the Indian subcontinent and Southeast Asia, respectively (Rogers and Padhye 2015; Shu et al. 2018; Vanjare et al. 2024). *Streptocephalus simplex* is the second most common species in the Indian subcontinent (Belk and Esparza 1995; Padhye et al. 2017). All the other species, including *S. longimanus*, *S. echinus*, *S. spinifer*, *S. siamensis* Sanoamuang & Saengphan, 2006, *S. shinsawbuae*, and *S. sahyadriensis*, appear to be limited to specific regions (Belk and Esparza 1995; Rogers and Padhye 2015; Padhye et al. 2017; Shu

Table 1. Brief comparison of important distinguishing characters of *Streptocephalus warliae* sp. nov. with *S. sirindhornae*, *S. sahyadriensis,* and *S. dichotomus*.

Characters	*S. warliae* sp. nov.	*S. sirindhornae* (Sanoamuang et al. 2000; Shu et al. 2015)	*S. sahyadriensis* (Rogers and Padhye 2014, and our specimens)	*S. dichotomus* (Vanjare et al. 2024, and our specimens)
distinct basomedial projection	Triangular	cylindrical	Absent	Absent
Length of the female first antenna	~2.4 of eye plus peduncle ~1.2 of second antenna	–	~1.4 of eye plus peduncle ~1.0 of second antenna	~1.7 of eye plus peduncle ~1.7 of second antenna
Female second antenna length: breadth ratio; apical end	>1.9, elongated; deep notch	–	~1.7, slightly elongated; notch absent, small triangular protrusion	~1.5, not elongated; notch absent, distinct triangular protrusion
protuberances on peduncle	ventral and anterio-medial side triangular, medial spiny	ventral absent, anterio-medial side triangular,	Absent	Ventral and anterio-medial absent, medial spiny
Depression on posterior ramus	Deep	Deep	Deep	Shallow
distal lamellar projection on the anterior ramus	Absent	Absent	Present	Present
Lower ramus: upper ramus ratio	>0.6 (upper more than twice length of shorter)	< 0.5 (upper less than twice length of shorter)	–	< 0.4 (strongly asymmetric)
Angle of the posterior primary branch to upper ramus	Sharp 90°	~50–70°	–	< 90°
posterior primary branch margin	With aciculate minor and major spines	Both spines absent, with pustulation	minor spines present, major spines tumid basally and aciculate distally	minor and major spines present but not tumid basally
Upper ramus margin	Pustulation present	Pustulation present	Pustulation present	Absent
Lower ramus margin	With spines	Spines absent, with pustulation	–	Spines and pustulation absent

et al. 2018). All endemics within the Indian subcontinent are known to exist in peninsular India (Central and South Zones sensu Padhye et al. 2017). This appears to be a result of undersampling rather than an actual trend. Climatic factors and geochemical or local environments affect anostracan distributions (Rogers 2014a; Rogers 2014b; Padhye et al. 2017), with the latter also driving speciation within the group ('anagenesis' sensu Rogers 2015). This is evident in the NWG, where *S. dichotomus* and *S. sahyadriensis* have limited distributions based on rock substrate, with no co-occurrences reported so far (authors, pers. obs.), the former being found in basaltic pools and the latter exclusively in lateritic pools (Padhye and Dahanukar 2015). We did not study the soil geochemistry at the type locality of *S. warliae* sp. nov., although it is presently known from the far northern region of the Northwestern Ghats. Additional environmental, genetic, and occurrence data regarding the endemic species are necessary to establish a consensus on which of the three evolutionary forms (allopatry, cladogenesis, and anagenesis) (Rogers 2015) may be influencing the speciation and distribution of fairy shrimp in the area.

A significant portion of Asia, particularly the Indian subcontinent, remains inadequately explored, with a high possibility of discovering additional populations and/or potentially new species in areas such as the Western Ghats (Rogers et al. 2013; Rogers and Padhye 2014). *Streptocephalus warliae* sp. nov. now represents the third endemic large branchiopod and the second endemic *Streptocephalus* species (along with *Leptestheria gurneyi* Padhye & Ghate, 2016, and *S. sahyadriensis*) discovered from the NWG in recent years. These results, coupled with the discovery of a few other new species (*Eulimnadia bondi* Padhye, Rabet, Kulkarni & Pagni, 2018; *L. gomantaki* Padhye, Kulkarni, Pagni & Rabet, 2023; *L. chalukyae* Padhye, Kulkarni, Pagni & Rabet, 2023), support the hypothesis of a 'Linnean shortfall' in the area (see Hortal et al. 2015; Modak et al. 2018).

Since we were unable to sequence further specimens and the molecular phylogenetic analysis was not sufficiently informative, we provide the sequences for the three *Streptocephalus* species that are found in Maharashtra, India (Suppl. material 1). However, integrative taxonomic studies employing both morphological and DNA data could help in understanding cryptic diversity within widespread species such as *S. dichotomus*, *Triops granarius*, and others (Lucas, 1864) (Modak et al. 2018; Vanjare et al. 2024).

The finding of an additional fairy shrimp from the Western Ghats highlights the importance of conducting long-term, comprehensive research on the biodiversity and distribution of large branchiopods, similar to efforts in Africa, North America, and SEA (Padhye et al. 2017; Shu et al. 2018).

We provide a continuation to the key by Rogers and Padhye (2014) for the Indian *Streptocephalus*.

A continuation to the key by Rogers and Padhye (2014) for the Indian *Streptocephalus*

1 Second antenna distal antennomere with a basomedial projection 2
1' Posterior primary branch margin of second antenna with minor and major aciculate spines; lower ramus margin of the 'bifid' tip with spines; India ..... *Streptocephalus warliae* sp. nov.
1" Posterior primary branch margin of second antenna with protuberances instead of spines; lower ramus margin of the 'bifid' tip with pustulations; Myanmar, Cambodia, Laos, Thailand; Southern China ..... *Streptocephalus sirindhornae* Sanoamuang et al. 2000
2 Second antenna distal antennomere lacking a basomedial projection; India, Myanmar, Pakistan, Sri Lanka ..... *Streptocephalus dichotomus* Baird, 1860

Author contribution

PMK: Investigation, methodology; SMP: Conceptualisation, data curation, formal analysis, investigation, methodology, supervision, visualisation, writing – original draft, writing – review and editing; AIV: Conceptualisation, data curation, formal analysis, funding acquisition, investigation, methodology, project administration, resources, supervision, visualisation, writing – original draft, writing – review and editing.

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Supplementary material 1

DNA extraction, PCR amplification and sequencing

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Data type: docx

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